DEPARTMENT OF ELECTRONICS AND ELECTRICAL COMMUNICATIONS ENGINEERING (EEC)
FACULTY OF ENGINEERING
TANTA UNIVERSITY

EEC3213: Optical Communications Photodetectors

Problem Set

Mahmoud Selim

April 3, 2016

P1: If the absorption coefficient of Si at wavelength of 0.9μm is 370 cm^{-1}. Determine the ratio of the optical power absorbed w.r.t. incident optical power P_0 for depletion layer width of $1, 5, 10, 20$ and 50μm over the corresponding wavelength.

P2: If an optical power level P_0 is incident on a photodiode, the electron hole-pair generated rate G(x) in the photodetector is given by

$$G(x) = \Phi_0 \alpha_s e^{-\alpha_s x}$$

Such that Φ_0 is the incident photos flux per unit area given by

$$\Phi_0 = \frac{P_0(1 - R_f)}{Ah\nu}$$

where A is the detector area. Show that the primary photocurrent generated in the depletion region of width w is given by

$$I_p = \frac{q}{h\nu} P_0(1 - R_f)(1 - e^{-\alpha_s w})$$

P3: Assuming that the value obtained in **P1** is a measurement of quantum efficiency. Determine the corresponding responsivity over that same wavelength of 0.9μm assuming a 20μm thick depletion layer and $R_f = 0$.

P4: If the low frequency gain M_0 of an avalanche photodiode, for applied voltages near the breakdown voltage, V_B, can be approximated by

$$M_0 = \frac{I_M}{I_P} \simeq \frac{V_B}{nI_M R_M}$$

where I_M is the total multiplied current, R_M accounts for the photodiode series resistance and the load resistor and n is an exponential factor depends on the semiconductor material and its doping profile.
Show that the maximum value of M_0 occurs at

$$M_{0,max} = \left(\frac{V_B}{nI_P R_M}\right)^{1/2}$$

P5: Consider a sinusoidally modulated optical signal P(t) of frequency ω, modulation index m, and average power P_0 given by

$$P(t) = P_0(1 + mcos\omega t)^2$$

Show that when this optical signal falls on a photodetector, the mean-square signal current $< i_s^2 >$ generated consists of a dc (average) component I_P and a signal current i_p given by

$$< i_s^2 >= I_P^2 + < i_p^2 >= (R_0 P_0)^2 + \frac{1}{2}(mR_0 P_0)^2$$

where R_0 is the responsivity.

P6: Consider an avalanche photodiode receiver that has the following parameters: dark current I_D = 1 nA, leakage current I_L = 1 nA, quantum efficiency η = 0.85, gain M = 100, excess noise factor $F = M^{1/2}$, load resistor $R_L = 10^4\Omega$, and bandwidth B = 10 KHz. Suppose a sinusoidally varying 850-nm signal having a modulation index $m = 0.85$ falls on the photodiode, which is at room temperature (T = 300 K. To compare the contributions form the various noise terms, compute the following various signal-to-noise components ratio: $\left(\frac{S}{N}\right)_Q$, $\left(\frac{S}{N}\right)_{DB}$, $\left(\frac{S}{N}\right)_{DS}$ and $\left(\frac{S}{N}\right)_T$ for this parameter set.

P7: For the parameter set in **P6**, if an average optical power level $P_0 = -50$ dBm falls on the detector. Calculate the optimal value of M for maximum signal-to-noise ratio.

P8: Suppose we have a silicon *pin* photodiode which has a depletion layer width $w = 20\mu$m, an area $A = 0.05$ mm^2, and a dielectric constant $K_s = 11.7$. If the photodiode is to operate with a 10 $K\Omega$ load resistor at 800 nm, where the absorption coefficient $\alpha_s = 10^3$ cm^{-1} and the drift speed is limited to the hole speed of 4.4×10^6 cm/s.
(a) Compare the RC time constant and the carrier drift time of the device?
(b) Is carrier diffusion time of importance in this photodiode?